

Intelligent Systems Reference Library 103

Alina Bărbulescu

# Studies on Time Series Applications in Environmental Sciences

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Alina Bărbulescu  
Ovidius University of Constanta  
Constanta  
Romania

ISSN 1868-4394 ISSN 1868-4408 (electronic)  
Intelligent Systems Reference Library  
ISBN 978-3-319-30434-2 ISBN 978-3-319-30436-6 (eBook)  
DOI 10.1007/978-3-319-30436-6

Library of Congress Control Number: 2016933239

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# **Intelligent Systems Reference Library**

Volume 103

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e-mail: kacprzyk@ibspan.waw.pl

Lakhmi C. Jain, Bournemouth University, Fern Barrow, Poole, UK, and

University of Canberra, Canberra, Australia

e-mail: jainlc2002@yahoo.co.uk

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*To Prof. Dr. Eng. Radu Dobrot—  
To **the One**,  
that made me laugh in the most difficult  
moments,  
that encouraged and supported me—  
with all my gratitude and love*

# Preface

Modeling and forecasting hydro-meteorological time series are of great interest due to their practical applications and impact on the human life. Many methods have been successfully used for solving different types of problems in this area. Here, we try only to summarize some possible approaches and to present a part of our results concerning modeling particular hydrological time series, from a region less studied in Europe.

The book is divided into seven chapters. In the first one we introduce the data series. The next two chapters are mainly theoretical. They contain some tests used for checking different statistical hypotheses on univariate time series and their implementation in R software, as well as a very short overview on the modeling techniques applied in the next chapters.

The rest of this book contains a part of our results, obtained the last 7 years on modeling the precipitation series or applications of some methods proposed by other scientists for generation precipitation fields.

One chapter summarizes the results of modeling the pollutants' dissipation in the atmosphere, while another one summarizes that of the evolution of water quality of two lakes, which are known to be affected by the atmospheric pollution and human activities.

All models refer to series from Dobrogea, a region situated in the southeastern part of Romania, between the Black Sea and the Danube River, for which no systematic study of climatic evolution has been done till 2007.

Scientific research is usually a team work, so a part of the results presented here has been obtained in cooperation with Dr. Lucica Barbeș, Dr. Elena Băutu, Dr. Judicael Deguenon, Dr. Cristina Gherghina, Dr. Carmen Elena Maftai, Dr. Elena Pelican, Dr. Nicolae Popescu-Bodorin, and Dr. Dana Simian. Thanks for their cooperation.

All the gratitude goes to Prof. Dr. Eng. Radu Victor Drobot, my Ph.D. supervisor in Civil Engineering. Without his valuable suggestions on different research topics and his continuous encouragement, this book wouldn't exist.

Thanks to Dr. Lakhmi Jain for his invitation to write this book.

Last but not least, thanks to my family that supported me unconditionally.

Sharjah, UAE  
October 2015

Alina Bărbulescu



# Data Series

The study region is Dobrogea, which is situated in the southeastern part of Romania, between the Black Sea and the Danube River, between 27°15'05" and 29°30'10" Eastern longitude and 43°40'04" and 45°25'03" Northern latitude. It has a surface of 11,145 km<sup>2</sup> without the Danube Delta and the lake basin Razim-Sinoe [7] (Fig. 1).



**Fig. 1** Dobrogea region, and the hydrological and hydro-meteorological stations. The main stations have roman letters attached

Its active surface is not uniform and it presents interesting geo-morphological characteristics. Since the presentation of these features is out the scope of this book, we invite the interested readers to refer to [4, 7].

The average annual temperature is 11 °C in the western part of the territory and is over 11 °C in its northeastern and northern parts. The mean annual temperature decreases from south to north, concomitantly with the altitude increasing and the augmentation of the continental influence inside region [5].

Different aspects related to the temperature variations and modeling of climate in this region can be found in [1–3, 6].

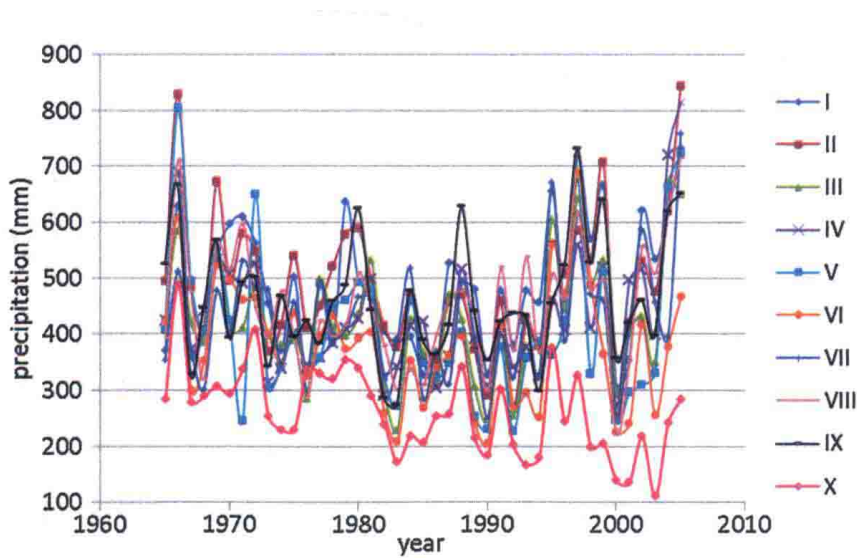


Fig. 2 Annual precipitation series recorded at the main stations

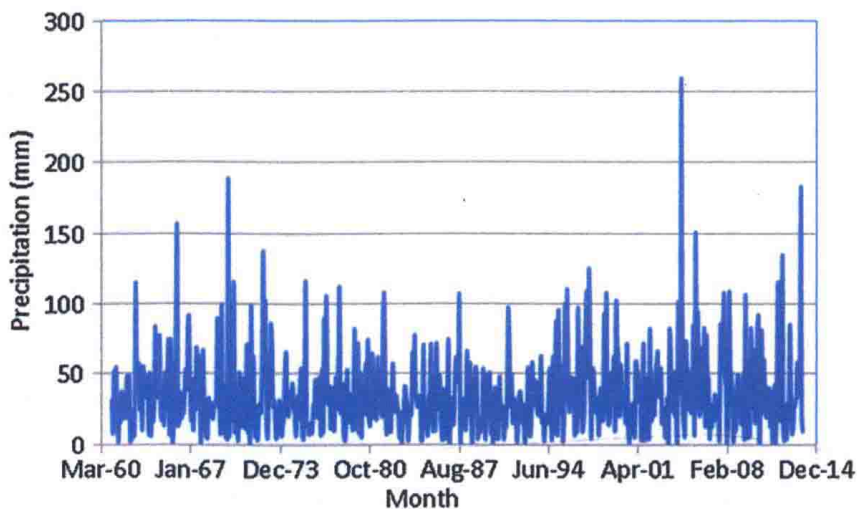


Fig. 3 Constanta monthly precipitation series (January 1961–December 2013)

The annual and monthly series studied here are recorded in the period January 1965–December 2005 at the ten main stations (that has a roman letter attached on the map on Fig. 1) and 41 secondary ones. In Fig. 2, we present the annual series of precipitation record in the period 1995–2005. For some series, as Constanta (Fig. 3) and Sulina, longer periods are used. All the series are complete, without gaps and reliable, collected by INHGA or from <http://eca.knmi.nl/>.

## References

1. Bărbulescu, A.: Modeling temperature evolution. Case study, Romanian Reports in Physics, **68**(1), (2016) (to appear)
2. Bărbulescu, A., Băutu, E.: ARIMA and GEP models for climate variation, International Journal of Mathematics and Computation, **3**(J09), pp. 1–7 (2009)
3. Bărbulescu, A., Băutu, E.: Mathematical models of climate evolution in Dobrudja, Theoretical and Applied Climatology, **100**(1–2), pp. 29–44 (2010)
4. Bărbulescu, A., Deguenon, J., Teodorescu, D.: Study on Water Resources in the Black Sea Region, Nova Publishers, USA (2011)
5. Bărbulescu, A., Teodorescu, D., Deguenon, J.: Study on water resources in the Romanian Black Sea region. In Ryann, A.M., Perkins, N.J. (eds), The Black Sea: Dynamics, Ecology and Conservation, pp. 175–205. Nova Publishers, USA (2011)
6. Maftai, C., Bărbulescu, A.: Statistical analysis of climate evolution in Dobrudja region, World Congress on Engineering, Imperial College of London, England, July 02–04, 2008, Book series: Lecture Notes in Engineering and Computer sciences, vol. II, pp. 1082–1087 (2008)
7. Posea, G., Bogdan, O., Zăvoianu, I.: Geografia României, vol. V, Editura Academiei Române, Bucuresti, (2005) (in Romanian)

# Contents

<b>1</b>	<b>Hypotheses Testing on Meteorological Time Series</b>	<b>1</b>
1	Normality Tests	1
2	Homoskedasticity Tests	7
3	Autocorrelation Tests	9
4	Outliers' Detection	15
5	Change Points' Detection	19
6	Testing for Long Range Dependence Property	31
7	Goodness of Fit Tests	42
	References	45
<b>2</b>	<b>Mathematical Methods Applied for Hydro-meteorological Time Series Modeling</b>	<b>51</b>
1	Types of Models. Classical Decomposition Method	52
2	Box-Jenkins Approach and Stationarity Tests	55
2.1	Box-Jenkins Approach	55
2.2	Stationarity Tests	61
3	Genetic Algorithms	66
3.1	Gene Expression Programming	67
3.2	Adaptive Gene Expression Programming	69
4	Support Vector Regression (SVR)	70
5	General Regression Neural Network (GRNN)	71
6	Wavelets	72
	References	74
<b>3</b>	<b>Models for Precipitation Series</b>	<b>79</b>
1	ARMA Models for Precipitation Series and Generation of Precipitation Fields	79
1.1	ARMA Models for Precipitation Series and Generation of Annual Precipitation Fields	79
1.2	Generation of Monthly Precipitation Series	91



2	Modeling and Forecast Using GEP, AdaGEP, SVR, GRNN and Hybrid Models . . . . .	105
3	Decomposition and Wavelets Models . . . . .	111
	References . . . . .	118
<b>4</b>	<b>Modeling the Precipitation Evolution at Regional Scale . . . . .</b>	<b>121</b>
1	On the Correlation and Predictability of Precipitation at Regional Scale. . . . .	121
2	Modeling the Regional Precipitation. . . . .	126
2.1	Models for the Regional Annual and Monthly Precipitation Series . . . . .	128
2.2	Models for the Regional Monthly Maximum Annual Precipitation . . . . .	131
3	Generation of Annual Precipitation Field at Regional Scale. . . . .	138
3.1	Overview of Some Theoretical Approaches. . . . .	138
3.2	Application to Annual Precipitation in Dobrogea Region. . . . .	140
	References . . . . .	142
<b>5</b>	<b>Analysis and Models for Surface Water Quality . . . . .</b>	<b>145</b>
1	On the Hydrochemical Properties of the Water of Techirghiol Lake . . . . .	146
2	On the Temperature of the Water of Techirghiol Lake . . . . .	149
	References . . . . .	150
<b>6</b>	<b>Models for Pollutants Dissipation . . . . .</b>	<b>153</b>
1	GRNN Models . . . . .	154
2	Linear Models. . . . .	156
	References . . . . .	157
<b>7</b>	<b>Spatial Interpolation with Applications . . . . .</b>	<b>159</b>
1	Theoretical Considerations on the Spatial Interpolation Methods . . . . .	159
1.1	Mechanical Methods . . . . .	160
1.2	Statistical Methods . . . . .	163
2	Applications of the Spatial Interpolation Methods . . . . .	167
2.1	The Most Probable Precipitation Method . . . . .	167
2.2	Spatial Interpolation of Maximum Annual Precipitation . . . . .	173
2.3	Spatial Interpolation of the Parameters in the AR Models for the Annual Precipitation Series . . . . .	176
	References . . . . .	186

# Chapter 1

## Hypotheses Testing on Meteorological Time Series

Data analysis is an important step in time series modeling and forecasting. It requires: obtaining and preparing the dataset, exploratory analysis of data series, performing statistical tests and the results' interpretation, the former being of major importance for all the other stages of analysis. Dealing with hydro-meteorological time series requires attention to data acquisition (measurement methodology and frequency), the series length (at least 50 years, in the case of studies concerning the climate change) and their completeness [105].

In this chapter, we focus on testing some statistical hypothesis and methods of detecting the long range dependence property in hydro-meteorological time series.

In what follows we denote the observed data by  $(x_i)_{i=1,n}$ . They are realizations of a time series process, denoted by  $(X_i)_{i=1,n}$ .

### 1 Normality Tests

The Gaussian distribution is well-known, its properties being established for many years ago. It is a reference distribution to which one may report the experimental data to discover their properties. Testing the series normality is also important because many statistical methods rely on the hypothesis that the series are Gaussian.

The simplest way to check the null hypothesis ( $H_0$ : the series is normally distributed) against its alternative ( $H_1$ : the series is not normally distributed) is the use of graphical representations. One of them is the quantile–quantile plot (Q-Q plot) employed for deciding whether a univariate random sample comes from a given distribution  $G$ . The Q-Q plot is obtained by plotting the quantiles of the sample against the theoretical quantiles of  $G$ . If the sample comes from the specified distribution (in our case, the Gaussian one) then the points are close to a straight line.

MINITAB, SPSS, R have the option to draw the Q-Q plot. We mention that R is freeware software.

In the following we present the R code for obtaining the Q-Q plot of Constanta annual precipitation series (1961–2013).

```
data<- read.csv("D:\\Lucrari_2.12.14\\2015_Carte\\Cta_annual_1961_2013.csv", sep=";",
header=TRUE)
qqnorm(y); qqline(y, col = 2)
```

Looking to the chart (Fig. 1a) we could not reject  $H_0$ . We couldn't also decide the opposite since the points from the upper part of the Q-Q plot are not very close to the line.

The same decision could be taken, looking to the histogram of the series (Fig. 1b), which is a two-dimensional representation of the observed data against their frequency.

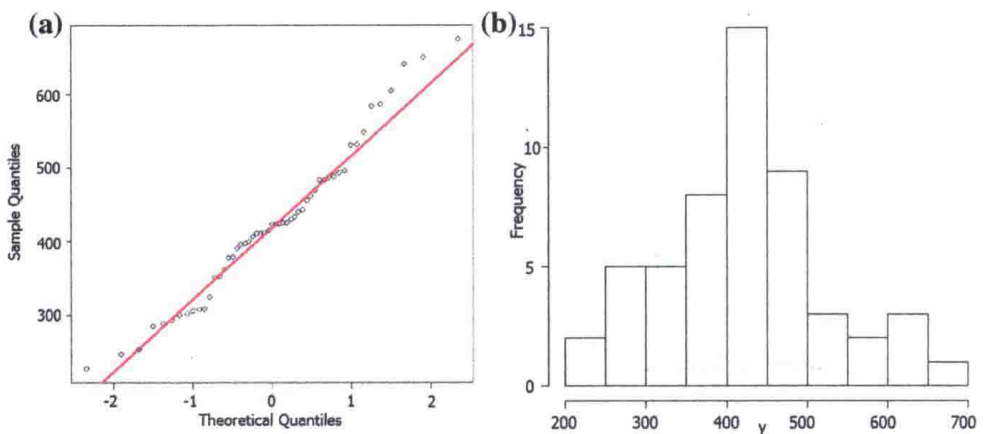
The R-function used to create the histogram is: `hist(y, right=FALSE)`.

The decision to reject the normality hypothesis can be taken very easy for Constanta monthly series (1961–2013) because the plots significantly deviate from the straight line and the histogram is right-skewed (Fig. 2).

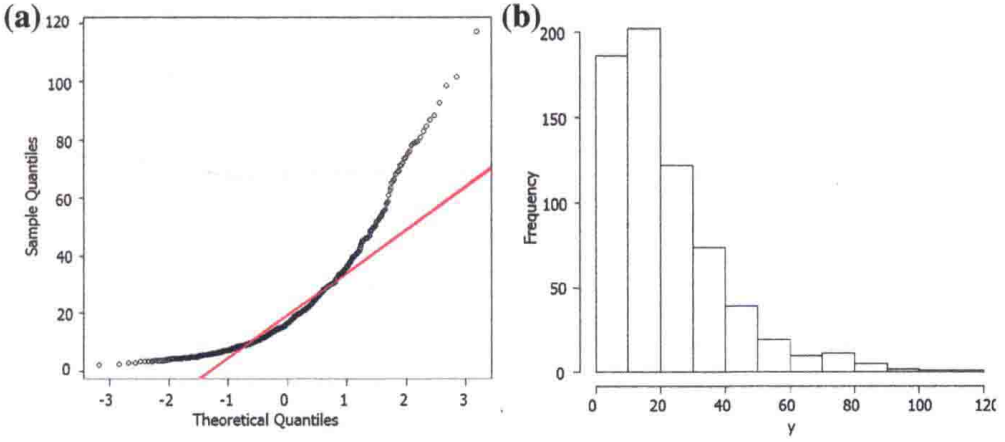
Since the decision on data normality is still difficult for Constanta annual series, other methods, based on statistical tests, are more appropriate. Among the tests used for this aim we mention: Kolmogorov–Smirnov [78, 111], Jarque–Bera [72], Shapiro–Wilk [110], Lilliefors [82] (presented in detail in [7]), Anderson–Darling [2] and Cramer von Mises [113].

The *Anderson–Darling test* is used to determine if a dataset comes from a specified distribution (the normal one, in our case), so it is considered to be also a goodness of fit test. It compares the fit of an observed cumulative distribution function to the expected cumulative distribution function.

Considering the sample data  $\{x_i\}_{i=1,n}$ , and  $\{x_{(i)}\}_{i=1,n}$  its values increasingly ordered, the Anderson–Darling statistic is defined by:



**Fig. 1** a Q-Q plot and b histogram of Constanta annual precipitation series (1961–2013)



**Fig. 2** **a** Q-Q plot and **b** histogram of Constanta monthly precipitation series (1961–2013)

$$A^2 = -n - \frac{1}{n} \sum_{i=1}^n (2i-1) [\ln F(x_{(i)}) + \ln(1 - F(x_{(n-i+1)}))], \quad (1)$$

where  $F$  is the cumulative distribution function of the specified distribution.

If Anderson–Darling is used as normality test, (1) becomes:

$$A^2 = -n - \frac{1}{n} \sum_{i=1}^n (2i-1) [\ln p_{(i)} + \ln(1 - p_{(n-i+1)})],$$

where:

$$p_{(i)} = \Phi([x_{(i)} - \bar{x}]/s), \quad (2)$$

$\Phi$  being the cumulative distribution function of the standard normal distribution,  $\bar{x}$ , the mean and  $s$ —the standard deviation of  $\{x_i\}_{i=1,n}$ .

The Cramer-von Mises test for the composite hypothesis of normality is also based on the cumulative distribution function. The test statistic is:

$$W = \frac{1}{12n} + \sum_{i=1}^n \left( p_{(i)} - \frac{2i-1}{2n} \right),$$

where  $p_{(i)}$  is given in (2).

The Pearson chi-square test for normality is applied to binned data so that the value of the statistic of the test depends on how the data was binned. Firstly, the data are standardized by subtracting the sample mean and dividing each value by



the sample standard deviation. Then, the number of bins ( $k$ ) is chosen by a formula (there is no optimal formula for this choice!), as, for example,  $k = 1 + \log_2 n$ , where  $n$  is the sample data.

The test statistic is:

$$\chi^2 = \sum_{i=1}^k (o_i - e_i)^2 / e_i,$$

where  $o_i$  is the observed frequency of the  $i$ th bin,  $e_i$  is the expected frequency of the  $i$ th bin, calculated by:

$$e_i = F(x_2) - F(x_1),$$

$F$  is the cumulative distribution function of the distribution being tested, and  $x_1, x_2$  are the limits of the  $i$ th bin.

When the mean and variance are known, the test statistic is asymptotically  $\chi^2$  distributed with  $k - 1$  degrees of freedom. Therefore, the null hypothesis is rejected at a significance level  $\alpha$  if the test statistic is greater than the quartile  $\chi^2_{1-\alpha}(k - 1)$ .

Simulation studies showed that the normality tests have different powers. The relative powers of the discrete statistics tests of Kolmogorov–Smirnov, Cramér–von Mises, Anderson–Darling and Watson and of two test statistics for nominal data (chi-square and Kolmogorov–Smirnov) for an uniform null distribution against a selection of fully specified alternative distributions has been studied in [112]. The results show that the Pearson's chi-square [96] and the nominal Kolmogorov–Smirnov are more powerful for the studied triangular, sharp and bimodal alternative distributions.

In the same idea, to compare the power of the Shapiro–Wilk, Kolmogorov–Smirnov, Lilliefors and Anderson–Darling tests, the Monte Carlo procedure was employed in [102]. The results proved that the least powerful test is the Kolmogorov–Smirnov one, and the most powerful one, Shapiro–Wilk, followed by Anderson–Darling. However, the Shapiro–Wilk test is biased if the sample size and the significance level are small (that is the power could be less than  $\alpha$ ). Due to its inferior power by comparison to the other tests, it is not advisable to use the Pearson chi-square test for checking the composite hypothesis of normality [62, 91].

In the following, the statistical tests are performed at a significance level of 0.05, if another level is not specified.

To perform normality tests using the R software, one has to install the packages **fBasics** [55] and **nortest** [62] and to write the following commands: